

THIS – a Next Generation Tuneable Heterodyne Infrared Spectrometer for SOFIA

Guido Sonnabend*

NASA Goddard Space Flight Center, Code 693, Greenbelt, MD 20771, USA

Daniel Wirtz, Rudolf Schieder

I. Physikalisches Institut, Universität zu Köln, Zùlpicher Str.77, 50937 Köln, Germany

ABSTRACT

A new infrared heterodyne instrument has been developed which allows the use of both tuneable diode lasers (TDL) and quantum cascade lasers (QCL) as local oscillators (LO). The current frequency tuning range of our system extends from 900 to 1100 cm^{-1} depending on the availability of lasers but is planned to be extended to 600 cm^{-1} soon. The IF-bandwidth is 1.4 GHz using an acousto-optical spectrometer (AOS). The frequency resolution and stability of the system is approximately 10^7 . Currently, mercury-cadmium-telluride (MCT) detectors are used as mixers while new devices like quantum-well-infrared-photodetectors (QWIP) and hot-electron-bolometers (HEB) are investigated. The IF-bandwidth can be extended to about 3 GHz by using a new broadband acousto-optical spectrometer presently under development. The instrument is fully transportable and can be attached to any infrared or optical telescope. The semiconductor laser is stabilized to a Fabry-Perot ring-resonator, which is also used as an efficient diplexer to superimpose the local-oscillator and the signal radiation. As a first step measurements of trace gases in Earth's atmosphere and non-LTE emission from Venus' atmosphere were carried out as well as observations of molecular features in sunspots. Further astronomical observations from ground-based telescopes and the airborne observatory SOFIA are planned for the future. Of particular interest are molecules without a permanent dipole moment like H_2 , CH_4 , C_2H_2 etc.

INTRODUCTION

In recent years IR heterodyne spectroscopy proved to be a powerful tool for astrophysical and atmospheric studies (see ^{1,2,3} and references therein). Whenever high spectral resolution is required heterodyne systems are advantageous because of their high optical throughput compared to direct detection methods like Michelson interferometry. Valuable information was gathered in the Earth's atmosphere as well as in the atmospheres of other planets of the solar system. The possible compactness of a heterodyne system is another advantage.

Gas lasers have mostly been used as LOs and the sensitivity of those systems has been shown to come close to the quantum limit whereas the restriction to the fixed laser

* Contact information for G. Sonnabend- Email: samstag@ph1.uni-koeln.de

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frequencies, which allows only about 15% of the spectral range between 9 and 12 μm be covered, is the biggest disadvantage of gas lasers.

This major limitation was overcome by TDL which are available from 1 to 34 μm . Unfortunately, the system noise temperature of advanced TDL pumped systems is worse by a factor of 3-5 compared to gas laser systems which is due to the lack of laser power, incoherent background emission, and the critical response of TDL to optical feedback. Although most of these problems were solved at an earlier stage of the development of THIS the TDL technique turned out to offer no perspective for future improvements.

At this point with the QCL a newly developed device became available. These are unipolar lasers first experimentally realized in 1994⁴ turned out to be the ideal LO for a tuneable heterodyne system. They provide sufficient optical power to reach the shot-noise detection limit and the handling is more convenient compared to TDLs. Use of QCLs brought the performance of THIS to the level of CO₂-laser based systems. THIS is widely usable at Cassegrain, Nasmyth or Coudé foci of IR or optical telescopes and is intended to be a second generation instrument for the airborne observatory SOFIA.

THE INSTRUMENTAL SETUP

Heterodyne receivers in every wavelength regime work in a common way: The broadband radiation to be analysed is superimposed with the radiation of a mono-mode LO. At present we use a QCL emitting at 9.2 μm wavelength. The power provided by these devices ranges up to a 100 mW. As mixer we use a fast MCT photovoltaic detector which is optimised for a wavelength of 10.6 μm . Through combined detection of LO and

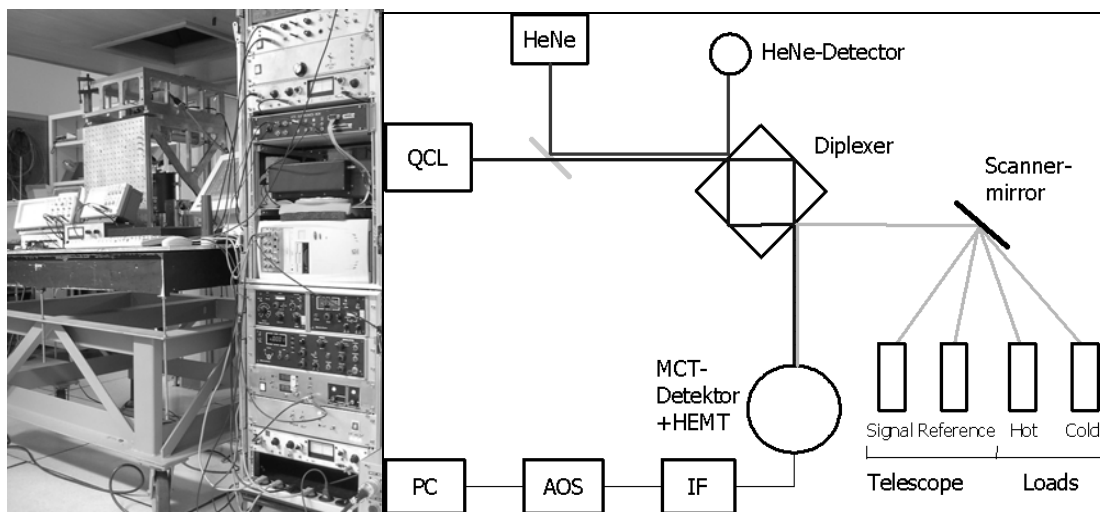


Fig. 1: left: THIS @ McMath-Pierce West Auxiliary: the optical receiver (cubic aluminum structure on the left) and back-end electronics (19"-rack on the right including the AOS) right: a schematic of the instrumental set-up showing the major components.

broadband signal the mixer generates an IF-signal that is amplified by a cooled high-electron-mobility-transistor amplifier (HEMT). Both devices are placed in a LN₂ cooled dewar. The Frequency analysis is done by a 2048 channel AOS with a total bandwidth of

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1.4 GHz.⁵ In order to avoid unnecessary losses of the LO power a confocal Fabry-Perot ring-resonator is used as diplexer to combine the LO with the broadband signal. Two focussing mirrors and two highly reflective beamsplitters make up the resonator. This device allows to superimpose about 60 % of LO power with more than 90 % of signal power.⁶

Direct calibration of the measured spectra is provided by occasionally switching between a 670 K blackbody emitter as hot load and an ambient temperature absorber as cold load. The transportable receiver (see fig. 1) consists of the optical setup (left) and the electronics (right). The optics (including the LO and the mixer) are mounted into a cubic frame made of aluminium with a size of roughly 60x60x40 cm³ and a weight of 80 kg which also allows THIS to be mounted into the focal plane of a Cassegrain telescope for example. Adaptation to different telescope focal lengths is done by a suitable off-axis parabolic mirror. Such mirrors are also used for matching the beam parameters of the LO, the mixer, and the diplexer. All electronic devices needed as well as the AOS back-end are mounted in an additional two part 19" rack. For convenient handling the receiver is remotely controlled through a personal computer that is also used for data acquisition

RESULTS

During November 2002 THIS was very successfully operated at the west auxiliary telescope of the McMath-Pierce Solar Observatory on Kitt Peak, Az. At first SiO and H₂O absorption lines in sunspots were measured. In Fig. 2 (left) one can see the rather odd line shape of this SiO absorption feature caused by contributions of different velocity components to the line.

To demonstrate the system sensitivity especially with regards to future astronomical

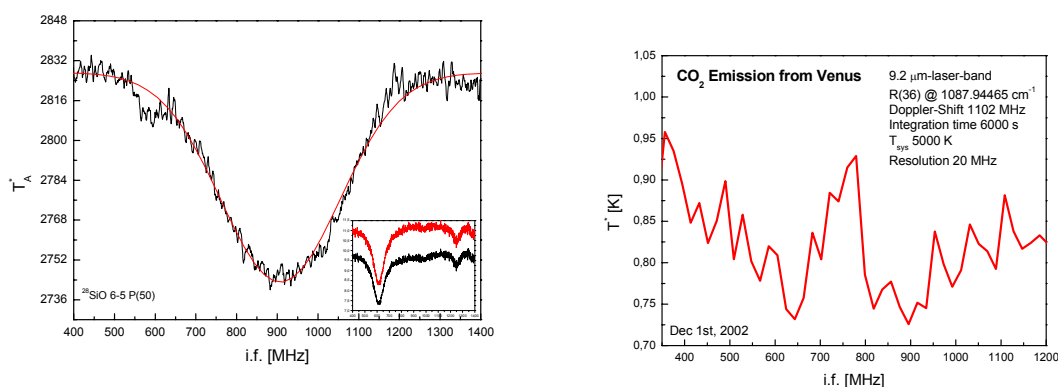


Fig. 2: left: SiO absorption feature in a sunspot. The line-profile yields a temperature of 5000 K. right: non-LTE emission from Venus. Shown is the R(36) line of the 9μm-band of CO₂.

observations we observed non-LTE emission features in the atmosphere of Venus. It is already known since the 1970s that natural non-LTE CO₂-emission is present at the illuminated arc. We were able to detect an emission signal of the R(36) transition of the 9 μm-band of CO₂ as can be seen in fig. 2 (right), shown with a resolution of 20 MHz. Again the detected brightness temperature is plotted against the intermediate frequency.

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One can see the emission peak sitting on a broad CO₂ – absorption that stems from lower altitudes of the Venus atmosphere. The measured brightness temperature (taken in account the losses mentioned above) is about 400 mK. Further evaluation especially a comparison to a calculated atmospheric model of Venus has to be done. Having been able to detect a weak non–terrestrial signal for the first time with THIS, we are looking forward to further observing runs in 2003.

THE FUTURE

Targets for future observations are ozone absorptions on Mars, which are of great interest for understanding the Martian atmosphere. Furthermore the non-LTE CO₂ emissions observations will continue in the atmospheres of Venus, Mars, and possibly in the Earth's atmosphere. We plan also to go to longer wavelengths as soon as LOs become available, since the sensitivity improves significantly. First step might be the 13μm lines of Acetylene one of the most abundant hydrocarbons on Jupiter. The long–term goal is the operation of THIS on the stratospheric observatory SOFIA from roughly 2007 on. The main goal here will be the detection of cold interstellar H₂ against moderately hot IR sources at wavelengths around 17 μm.

To reach the described goals technical developments of the laser LOs as well as the detectors are necessary. The laser development is mainly done by Alpeslasers, Switzerland. New detector technologies to be investigated are HEBs and QWIPs. HEBs are build in our institute and currently in the final test phase for infrared applications. Calculations yield good results up to 10 μm wavelength and bandwidth of up to 8 GHz. QWIP detectors made by Fraunhofer Institut für angewandte Festkörperphysik, Germany, showed a sensitivity of about 5 % in a first test. Newly designed devices are believed to have a quantum efficiency comparable to MCT detectors while having bandwidth' up to 10 GHz. To make use of the higher bandwidth a new broadband AOS is currently under development by BAE-Systems and our Institute.

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